14:17:59 OCA PAD INITIATION - PROJECT HEADER INFORMATION 08/11/88

Active

Project #: [redacted]
Center # : R6566-0A0
Cost share #: G-41-374
Center shr #: F6566-0A0
Rev #: 0
OCA file #:
Work type : RES
Document : CONT
Contract entity: GTRC

Contract [redacted]
Prime #:
Mod #:

Subprojects ? : N
Main project #:

Project unit: PHYSICS Unit code: 02.010.152
Project director(s):
[redacted]

Sponsor/division names [redacted]
Sponsor/division codes [redacted]

Award period: [redacted]

Sponsor amount	New this change	Total to date
Contract value	194,459.00	194,459.00
Funded	55,888.00	55,888.00
Cost sharing amount		80,063.00

Does subcontracting plan apply ?: N

Title: [redacted]

PROJECT ADMINISTRATION DATA

OCA contact: E. Faith Gleason 894-4820

Sponsor technical contact

DR. MICHAEL SCHLESINGER, PHYSICS DIV
(202)696-4220
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OFFICE OF NAVAL RESEARCH
800 NORTH QUINCY STREET
ARLINGTON, VA 22217-5000

Security class (U,C,S,TS) [redacted]
Defense priority rating : N/A
Equipment title vests with: Sponsor
ONR resident rep. is ACO (Y/N) [redacted]
GOVT supplemental sheet
GIT X
PRIOR APPROVAL REQUIRED UNLESS INCLUDED IN APPROVED PROPOSAL BUDGET.

Administrative comments - [redacted]

GEORGIA INSTITUTE OF TECHNO
OFFICE OF CONTRACT ADMINISTRA..

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NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 06/26/91

Project No. G-41-685 Center No. R6566-0A0

Project Director WIESENFELD K A School/Lab PHYSICS

Sponsor NAVY/OFC OF NAVAL RESEARCH

Contract/Grant No. N00014-88-K-0494 Contract Entity GTRC

Prime Contract No.

Title NONLINEAR DYNAMICS OF JOSEPHSON JUNCTION PARAMETRIC AMPLIFER ARRAYS

Effective Completion Date 910430 (Performance) 910630 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	
Final Report of Inventions and/or Subcontracts	Y	
Government Property Inventory & Related Certificate	Y	
Classified Material Certificate	N	
Release and Assignment	Y	
Other	N	

Comments:

Subproject Under Main Project No.

Continues Project No.

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
[redacted]	Y
GTRC	Y
Project File	Y
Other	N
	N

NOTE: Final Patent Questionnaire sent to PDPI.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
for
1 Oct 88 through 30 Sept 89

R&T Number: 4123050 – 03

Contract/Grant Number: N00014-88-K-0494

*NOTE PLEASE NOTE CORRECTED DATE

Contract/Grant Title: Nonlinear Dynamics of Josephson Junction Parametric Amplifier Arrays

Principal Investigator:

Mailing Address: Kurt Wiesenfeld
SCHOOL of PHYSICS
Georgia Institute of Technology
Atlanta, GA 30332

Phone Number: (with Area Code) (404) 894-2429

E-Mail Address: —

a. Number of Papers Submitted to Refereed Journal but not yet published: 3

b. Number of Papers Published In Refereed Journals: 5
(list attached)

c. Number of Books or Chapters Submitted but not yet Published: 0

d. Number of Books or Chapters Published: 1
(list attached)

e. Number of Printed Technical Reports & Non-Refereed Papers: 0
(list attached)

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0
(list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 0

i. Number of Presentations at Workshops or Prof. Society Meetings: 1

j. Honors/Awards/Prizes for Contract/Grant Employees:
(list attached, this might include Scientific Soc Awards/Offices, Promotions, Faculty Awards/Offices etc)

k. Total number of Graduate Students and Post-Docs Supported at least 25% this year on this contract/grant:
Grad Students 1 and Post-Docs 1.

How many of each are females or minorities? (These 6 numbers are for ONR's EEO/Minority Reports; minorities include Blacks, Aleuts AmIndians, etc and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting the varying report semantics re "economically disadvantaged").

- Grad Student Female 0
- Grad Student Minority 0
- Grad Stu Asian e/n 0
- Post-Doc Female 0
- Post-Doc Minority 0
- Post-Doc Asian e/n 0

Office of Naval Research
Publications/Patents/Presentations/Honors Report
for
1 Oct '88 through 30 Sept '89

Papers Published in Refereed Journals

1) "Phase Locking of Josephson Junction Series Arrays"
P. Hadley, M.R. Beasley, and K. Wiesenfeld
Physical Review B, vol. 38, pp. 8712-8719 (Nov. 1988).

2) "Noise Driven Fluctuations of Josephson Junction Series Arrays"
P. Hadley, M.R. Beasley, and K. Wiesenfeld
I.E.E.E. Transactions on Magnetics, vol. 25, pp. 1088-1091 (Mar. 1989).

3) "Attractor Crowding in Nonlinear Oscillator Arrays"
K. Wiesenfeld and P. Hadley
Physical Review Letters, vol. 62, pp. 1335-1338 (Mar. 1989).

4) "Theory of Stochastic Resonance"
B. McNamara and K. Wiesenfeld
Physical Review A, vol. 39, pp. 4854-4869 (May 1989).

5) "A Physicist's Sandbox"
K. Wiesenfeld, C. Tang, and P. Bak
Journal of Statistical Physics, vol. 54, pp. 1441-1458 (May 1989).

Chapter in a Book

"Period Doubling Bifurcations: What Good Are They?"
K. Wiesenfeld
Chapter 7, volume 2 in Noise in Nonlinear Dynamical Systems: Theory, Experiment, and Simulation, edited by F. Moss and P.V.E. McClintock; Cambridge University Press, 1989.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT G-41-625
for
1 Oct 89 through 30 Sept 90

R&T Number: 4123050-03

Contract/Grant Number: N00014-88-K-0494 *NOTE PLEASE NOTE CORRECTED DATE

Contract/Grant Title: Nonlinear Dynamics of Josephson Junction Parametric Amplifier Arrays

Principal Investigator: Kurt Wiesenfeld

Mailing Address: School of Physics
Georgia Institute of Technology
Atlanta, GA 30332

Phone Number: (with Area Code) (404) 894-2429

E-Mail Address: —

a. Number of Papers Submitted to Refereed Journal but not yet published: 5

b. Number of Papers Published in Refereed Journals: 4
(list attached)

c. Number of Books or Chapters Submitted but not yet Published: 0

d. Number of Books or Chapters Published: 0
(list attached)

e. Number of Printed Technical Reports & Non-Refereed Papers: 0
(list attached)

f. Number of Patents Filed: 0

g. Number of Patents Granted: 0
(list attached)

h. Number of Invited Presentations at Workshops or Prof. Society Meetings: 2

i. Number of Presentations at Workshops or Prof. Society Meetings: 4

j. Honors/Awards/Prizes for Contract/Grant Employees:
(list attached, this might include Scientific Soc Awards/Offices, Promotions, Faculty Awards/Offices etc)

k. Total number of Graduate Students and Post-Docs Supported at least 25% this year on this contract/grant:
Grad Students 1 and Post-Docs 1.

How many of each are females or minorities? (These 6 numbers are for ONR's EEO/Minority Reports; minorities include Blacks, Aleuts AmIndians, etc and those of Hispanic or Asian extraction/nationality. The Asians are singled out to facilitate meeting the varying report semantics re "economically disadvantaged").

- Grad Student Female 0
- Grad Student Minority 0
- Grad Stu Asian e/n 0
- Post-Doc Female 0
- Post-Doc Minority 0
- Post-Doc Asian e/n 1

Office of Naval Research
Publications/Patents/Presentations/Honors Report
for
1 Oct '89 through 30 Sept '90

Papers Published in Refereed Journals

1) "Attractor Crowding in Josephson Junction Arrays"
K.Y. Tsang and K. Wiesenfeld
Applied Physics Letters, vol. 56, pp. 495-496 (Jan.1990).

2) "Self-Organized Criticality in Vector Avalanche Automata"
B. McNamara and K. Wiesenfeld
Physical Review A, vol. 41, pp. 1867-1873 (Feb. 1990).

3) "Suppressed Fluctuations and Incipient Instabilities"
K. Wiesenfeld and J.S. McCarley
Physical Review A, vol. 42, pp. 755-760 (Jul. 1990).

4) "Self-Organized Criticality in a Deterministic Automaton"
K. Wiesenfeld, J. Theiler, and B. McNamara
Physical Review Letters, vol. 65, pp. 949-952 (Aug. 1990).

ONR FINAL TECHNICAL REPORT

"Nonlinear Dynamics of Josephson Junction Parametric Amplifier Arrays"

Contract Number: N00014-88-K-0494

Principal Investigator:
Kurt Wiesenfeld
School of Physics
Georgia Institute of Technology
Atlanta, GA 30332
(404) 894-2429

Date: June 19, 1991

Table of Contents

I. Summary of Work Accomplished

A. Introduction

The basic goal of the project was to investigate the behavior of Josephson junction arrays using theoretical tools from dynamical systems theory. Emphasis was placed on the stability of coherent operation of arrays, and their sensitivity near the onset of instabilities. Good progress has been made in these areas; all of this work has appeared (or is scheduled to appear) in the published literature: for a listing, see references 1-7 in Section III. This primary work is summarized in Section IB.

In addition, we were able to make progress on a number of other problems, which share mathematical features with the Josephson junction system. This was possible because the approach of dynamical systems theory extracts features which are not sensitive to the details of the physical system; consequently, these behaviors are typical of a broader class of systems. The results on these other topics also have been published in the technical literature: for a listing, see references 8-18 in Section III. This additional work is summarized in Section IC.

B. Josephson Junction Arrays.

For practical applications, it is most desirable to operate arrays in the *in-phase state*, so that each oscillator has precisely the same waveform, and all oscillators are in perfect synchrony. Consequently, the first order of business is to determine the conditions under which stable in-phase operation is possible. The stability regions for a variety of circuit configurations has been mapped out, first via numerical simulations[1] and then via approximate analytic calculations[2,3]. In fact, we discovered that for certain circuit designs, the dynamics possessed a fundamental symmetry that prohibits stable in-phase orbits[4,5]. We conclude immediately that such designs should be avoided for any practical

application. (For example, this applies to small capacitance "point contact" junctions shunted by a purely resistive load.)

The next step taken was to investigate the response of the in-phase state to random fluctuations. For small noise strengths (corresponding to very low temperatures), the effects show up in two fundamentally different ways: (i) as broadening the sharp spectral lines, and (ii) as additional broadband "skirts" of Lorentzian character[6]. As the stability boundary is approached, these effects become increasingly strong -- that is, the quality of the output is degraded. How great is the degradation depends only on the symmetry properties of the nearing instability. In particular, if the instability corresponds to a symmetry breaking, we find a remarkable robustness possessed by the array: though each element suffers large-scale fluctuations, the total voltage oscillations across the array remain small! On the other hand, if the instability is symmetry preserving, the fluctuations become increasingly strong as the bifurcation is approached[7].

For use as parametric amplifiers, we also considered the array response to periodic perturbations (representing the input signal). Here, we found that substantial amplification is expected only in the case of symmetry preserving instabilities. In fact, the amplification of this extrinsic signal is expected to be greater than the degradation (mentioned above) due to intrinsic fluctuations as a function of increasing array size. Specifically, for an array consisting of N elements, the extrinsic signal enjoys a power gain proportional to N^2, while the intrinsic noise shows a gain in power proportional to N.

Finally, we discovered the possibility of a new kind of noise sensitivity that can affect an array of N junctions, which is absent for the single junction problem. This phenomenon, called attractor crowding[8,9], is the result of global dynamical considerations (in contrast with the local considerations described above). In particular, if the stable in-phase orbit coexists with a particular type of orbit called the splay-phase orbit (as is often the case in the Josephson circuits), then noise becomes increasingly effective at destroying the coherence of the array. Direct simulations of the circuit equations have verified this picture[9]. This problem can be avoided by operating the Josephson junction array in a parameter regime where no stable splay-phase orbits exist.

C. Additional Work

Globally Coupled Arrays. The primary spin-offs of the research on Josephson junction arrays rest on the structure of these equations, in particular the property of global coupling. This property allow certain general progress, which can also be applied to certain laser systems[10,11], and also to other systems[12]. The laser system we studied was a diode pumped Nd:YAG laser with an intracavity frequency-doubling crystal. We were able to predict the conditions under which stable steady-state behavior was expected[10], and also the appearance of splay-state orbits[11]. Both sets of predictions were directly verified by experiments carried out by R. Roy's group at Georgia Tech. In another project, we looked at a room temerature electrical circuit consisting of an array of p-n junctions, which has structural similarities with the Josephson junction array circuit. We tested whether certain combinatoric ideas might be useful in describing the degree of coherence exhibited by the array. In fact, the results were surprisingly encouraging[12], and we conclude that such a statistical approach might be valuable in handling cases where the array elements are not nearly identical.

Stochastic Resonance. This concerns the behavior of bistable dynamical systems which are driven by a strong noise source and a weak periodic modulation, and the possibility of improved signal-to-noise ratios as the input noise is increased. Previously, in collaboration with R. Roy, we demonstrated this effect in a laser experiment. The experiment set off a number of theoretical and experimental efforts, including the publication of our own detailed theory (which formed the second part of B. McNamara's Ph.D. dissertation)[13].

Self-Organized Criticality. This refers to a phenomenon observed in model spatially extended dynamical systems which (like the Josephson junction arrays) have large numbers of metastable states, where the statistical steady state is characterized both spatially and temporally by power law fluctuations. Considerable interest has been generated, since this offers a paradigm in which

the balance between steady external stress and internal transport results in complex spatial and temporal behavior, rather than a simple time-independent equilibrium. We established new examples of cellular automata which exhibit SOC[14], including the first case of a completely deterministic system[15]. We have also provided some of the first analytic results on the subject, and deduced that the "critical state" has the structure of a neutrally stable attractor in the appropriate phase space.

Classical Analog of Squeezed Fluctuations. Experiments by M. Bocko (U. Rochester) previously showed that a classical analog of the squeezed fluctuations observed in quantum optics can occur in a driven p-n junction near the onset of simple bifurcations. We developed a theory[16] showing that such squeezing is a generic property of a broad class of nonlinear systems which includes the one studied by Bocko. The theory suggests a limit to the maximum amount of squeezing, in contrast to (presumably more fundamental) quantum optical descriptions.

References

[1] P. Hadley, "Dynamics of Josephson Junction Arrays", Ph.D. dissertation, Stanford University (1989), unpublished.

[2] P. Hadley, M.R. Beasley and K. Wiesenfeld, Physical Review B, volume 38, pp. 8712-8719 (1988).

[3] S. Nichols, "Dynamical Stability in Josephson Junction Arrays", Masters Thesis, Georgia Institute of Technology (1990), unpublished.

[4] K.Y. Tsang, R.E. Mirollo, S.H. Strogatz, and K. Wiesenfeld, Physica D, volume 48, pp. 102-112 (1991).

[5] K.Y. Tsang, S.H. Strogatz, and K. Wiesenfeld, Physical Review Letters, volume 66, pp. 1097-1100 (1991).

[6] P. Hadley, M.R. Beasley, and K. Wiesenfeld, I.E.E.E. Transactions on Magnetics, volume 25, pp.1088-1091 (1989).

[7]. "Amplification by Globally Coupled Nonlinear Arrays: Coherence and Symmetry", K. Wiesenfeld, accepted for publication in Physical Review A (to appear, 1991).

[8] K. Wiesenfeld and P. Hadley, Physical Review Letters, volume 62, pp. 1135-1138 (1989).

[9] K.Y. Tsang and K. Wiesenfeld, Applied Physics Letters, volume 56, pp. 495-496 (1990).

[10] G.E. James, E. Harrell II, C. Bracikowski, K. Wiesenfeld, and R. Roy, Optics Letters, volume 15, pp. 1141-1143 (1990).

[11] K. Wiesenfeld, C. Bracikowski, G. James, and R. Roy, Physical Review Letters, volume 65, pp. 1749-1752 (1990).

[12] L. Fabiny and K. Wiesenfeld, Physical Review A, volume 43, pp. 2640-2648 (1991).

[13] B. McNamara and K. Wiesenfeld, Physical Review A, volume 39, pp. 4854-4869 (1989).

[14] B. McNamara and K. Wiesenfeld, Physical Review A, volume 41, pp. 1867-1873 (1990).

[15] K. Wiesenfeld, J. Theiler, and B. McNamara, Physical Review Letters, volume 65, pp. 949-952 (1990).

[16] K. Wiesenfeld and J.S. McCarley, Physical Review A, volume 42, pp. 755-760 (1990).

II. Personnel

During the period of the contract, several people who participated in the research described received support or partial support. Bruce McNamara is presently an Assistant Professor at Reed College in Portland, Oregon. Kwok Yeung Tsang is now a scientist at the Naval Research Laboratory in Washington, D.C. Each of these two individuals had filled the postdoctoral position funded by the grant. The grant has also been used at times to support two graduate students: Li-Shi Luo is scheduled to receive his Ph.D. by the end of the calendar year 1991; Steven Nichols completed his Masters thesis in the summer of 1990, and is presently working toward his Ph.D. in our group.

III. Index of Publications

The following is a list of all publications of the Principal Investigator during the period covered by the contract.

1. "Attractor Crowding in Oscillator Arrays", K. Wiesenfeld and P. Hadley, Physical Review Letters, volume 62, pp. 1135-1138 (March, 1989).

2. "Noise Driven Fluctuations of Josephson Junction Series Arrays", P. Hadley, M.R. Beasley, and K. Wiesenfeld, I.E.E.E. Transactions on Magnetics, volume 25, pp. 1088-1091 (March, 1989).

3. "Attractor Crowding in Josephson Junction Arrays", K.Y. Tsang and K. Wiesenfeld, Applied Physics Letters, volume 56, pp. 495-496 (January, 1990).

4. "Dynamics of a Globally Coupled Oscillator Array", K.Y. Tsang, R.E. Mirollo, S.H. Strogatz, and K. Wiesenfeld, Physica D, volume 48, pp. 102-112 (1991).

5. "Reversibility and Noise Sensitivity of Josephson Arrays", K.Y. Tsang, S.H. Strogatz, and K. Wiesenfeld, Physical Review Letters, volume 66, pp. 1097-1100 (February, 1991).

6. "On the Comparison Between Josephson Junction Array Variations", K.Y. Tsang and K. Wiesenfeld, accepted for publication in Journal of Applied Physics(to appear, 1991).

7. "Amplification by Globally Coupled Nonlinear Arrays: Coherence and Symmetry", K. Wiesenfeld, accepted for publication in Physical Review A (to appear, 1991).

8. "Theory of Stochastic Resonance", B. McNamara and K. Wiesenfeld, Physical Review A, volume 39, pp. 4854-4869 (May, 1989).

9. "A Physcist's Sandbox", K. Wiesenfeld, C. Tang, and P. Bak, Journal of Statistical Physics, volume 54, pp. 1441-1458 (1989).

10. "Period doubling bifurcations: what good are they?", K. Wiesenfeld, in Noise in Nonlinear Systems: Theory, Experiment, and Simulation, F. Moss and P.V.E. McClintock, editors (Cambridge University Press, Cambridge, 1989).

11. "Comment on 'Relaxation at the Angle of Repose'", P. Bak, C. Tang, and K. Wiesenfeld, Physical Review Letters, volume 62, pg. 110 (January, 1989).

12. "Self Organized Criticality in Vector Avalanche Automata", B. McNamara and K. Wiesenfeld, Physical Review A, volume 41, pp. 1867-1873 (February, 1990.)

13. "Suppressed Fluctuations and Incipient Instabilities", K. Wiesenfeld and J.S. McCarley, Physical Review A, volume 42, pp. 755-760 (July, 1990).

14. "Self Organized Criticality in a Deterministic Autamaton, K. Wiesenfeld, J. Theiler, and B. McNamara, Physical Review Letters, volume 65, pp. 949-952 (August, 1990).

15. "Elimination of Chaos in an Intracavity-Doubled Nd:YAG Laser", G.E. James, E. Harrell II, C. Bracikowski, K. Wiesenfeld, and R. Roy, Optics Letters, volume 15, pp. 1141-1143 (October 1990).

16. "Observation of Antiphase States in a Multimode Laser", K. Wiesenfeld, C. Bracikowski, G. James, and R. Roy, Physical Review Letters, volume 65, pp. 1749-1752 (October, 1990).

17. "Unfolding a Chaotic Bifurcation", O. Rossler, H.B. Stewart, and K. Wiesenfeld, Proceedings of the Royal Society of London A, volume 431, pp. 371-383 (1990).

18. "Clustering Behavior in Globally Coupled Oscillators", L. Fabiny and K. Wiesenfeld, Physical Review A, volume 43, pp. 2640-2648 (March, 1991).